Analysis of Automotive Sound: Is Bigger Really Better?

An Honors Thesis (MMP 495)

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Abstract:

In a world of portable digital media the environments in which we listen to music are becoming more and more diverse. One of the goals of the audio engineer is to create a product that listeners can enjoy in any environment. In my efforts to do this, I came to the realization that I needed a solid understanding of a variety of listening environments and how they affected the reproduction of recorded sound. Automobiles are a very common listening environment for music and other recorded medium; each automobile sound system applies its own sonic coloration to recordings. In this thesis, I will look at the sound systems in two vehicles, the 2015 Honda Fit LX and the 2015 Honda Fit EX to compare the input of the sound system with its output. I will use these tests to determine how well these models of car reproduce sound and compare the sound systems of the two vehicles to see how a "premium" sound system stands up against its "standard" counterpart. I will discuss options and suggestions for audio engineers who want to tailor products for the automotive environment.

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Analysis of Automotive Audio: Is Bigger Really Better?

We've all been there. You feel really good about the work after you finished the recording. The band seemed excited about it, and you couldn't wait to get to the mix stage. Since you had killer tracks, the mix came together easily. You finish up the best mix of your life, and now you want to hear it out in the real world. You take it outside to your car, put in the CD, and then:

"What happened?"

You knew it would sound different in the car. But this doesn't sound like your mix at all. The energy, fullness, and drive have been sapped from the track. You listen again in the studio, and everything is where you expect it to be. So again, you ask:

"What happened?"

Now you know that the car is the problem. But you want your mix to sound good anywhere, so what do you do? You don't even know why it sounds bad.

These days people are listening to music on the go more than ever. With smartphones, portable music players and satellite radio all easily available, it's becoming rare to ride in a quiet car. As audio engineers, it is important to create products that can be enjoyed in any environment, especially the less than ideal ones. Just as it's impossible to get a great recoding without a knowledge of acoustics, it's hard to know why cars affect sound without an understanding of what all is going on when you start the engine and turn on that stereo.

First a Bit of Background

Before we get into the testing of the car and the results some discussion of basic audio and acoustic principles is necessary. In later parts of this paper, graphs of a frequency spectrum will be presented. The human range of hearing spans from around 20 hertz to 20,000 hertz. These graphs cover the full range, showing the amplitude of each frequency. The way the full spectrum of audible sound fills any space is not uniform even with acoustic treatment. For this experiment, the microphone used to record the car sound system was put in the same place to minimize this difference in frequencies. On the accompanying CD, you can hear the recording of the outputs of the car sound systems with the engine off and on, and the audio samples used. Listening is subjective, so feel free to listen to the audio and reach your own conclusions about the performance.

You Get What You Pay For

When you buy a new car, what are you buying? Most auto manufacturers are in the car business, not the sound system business. Their goal is to design a good car, not an awesome listening space (although some do advertise this). The stock sound systems in most cars are manufactured cheaply unless you are paying for an upgraded model. As a result, the speakers that come with most cars are made of inexpensive materials, which deliver a poorer low and high frequency response. [1] This can translate to less punch and clarity, both of which are crucial to great music. Unfortunately for us audiophiles, most people don't pay the cost to upgrade their system with aftermarket speakers, and live with the suboptimal system. In a perfect world, everyone would upgrade their own car system, or auto manufacturers would make nicer systems standard.

Inside The Cabin

As important as the sound system is in determining what we will hear, the physical space plays just as much of a role. In spaces, the physical dimensions of the space emphasize certain frequencies, and as you move about the room those resonant frequencies change. A car is no different from any other enclosed space. Every car has different dimensions in the cabin, so the resonant frequencies and standing waves will occur at different frequencies and different locations. The surfaces in the car will also absorb or reflect frequencies, which will also affect these resonances depending on the materials and their thickness. Since every car is different, a mix will sound slightly different in every car.

Another thing to look at in the car is the speaker placement. Typically, a four-speaker car system contains two speakers placed in the front doors or on the dashboard console and two speakers placed in the back, often behind the back passenger seat. Given their locations, it's easy to predict that there will be uneven stereo imaging in just about any seat in the car with the possible exception of a middle seat. These off-center listening locations can cause nasty phase interferences, along with a distorted stereo image. [2] If your mix relies heavily on stereo effects and tricks like the Haas effect or the out-of-speaker effect, a car might not be very kind to those elements affected.

Is Bigger Really Better?

With all of this in mind, let's take a look at some automobile sound systems. I wanted to test a car and compare two models with different sound systems. I was curious how the "standard" model would stack up against a more expensive "premium" sound system. The 2015 Honda Fit offers two sound systems: a four-channel sound system that comes standard with every vehicle and a six-channel premium system. To test these, I made a demo reel containing featuring five different audio samples:

Pink Noise

White Noise

"Get Lucky" by Daft Punk (2013)

"Still Can Feel the Heat" by Train Company (2014)

"Symphony No. 9, Mvt. 2 (Beethoven, Conducted by Riccardo Muti, 2011)

"Empire State of Mind" by Jay Z (2009)

Sine wave sweep from 20 Hz- 20kHz

These recordings would help me identify differences in frequency responses, as well as provide musical examples of different genres to listen for the stereo field. It is not uncommon to test sound systems by playing back white and pink noise, and then referencing it with familiar recordings. [3] There are several characteristics of a system to look other than frequency response, such as phase, harmonic distortion, dynamic range, and noise issues. This paper will focus primarily on frequency response.

To record the playback of these recordings, I used a Shoeps MSTC 64 U microphone. This is a condenser microphone with a cardioid polar pattern. It is a stereo microphone with a fixed ORTF pattern. An ORTF pattern spaced to matched the human hearing and angled to match the directionality of human hearing. The very flat frequency response and stereo imaging of the microphone made it a great candidate for these tests. A diagram of the frequency response can be seen in Figure 1:

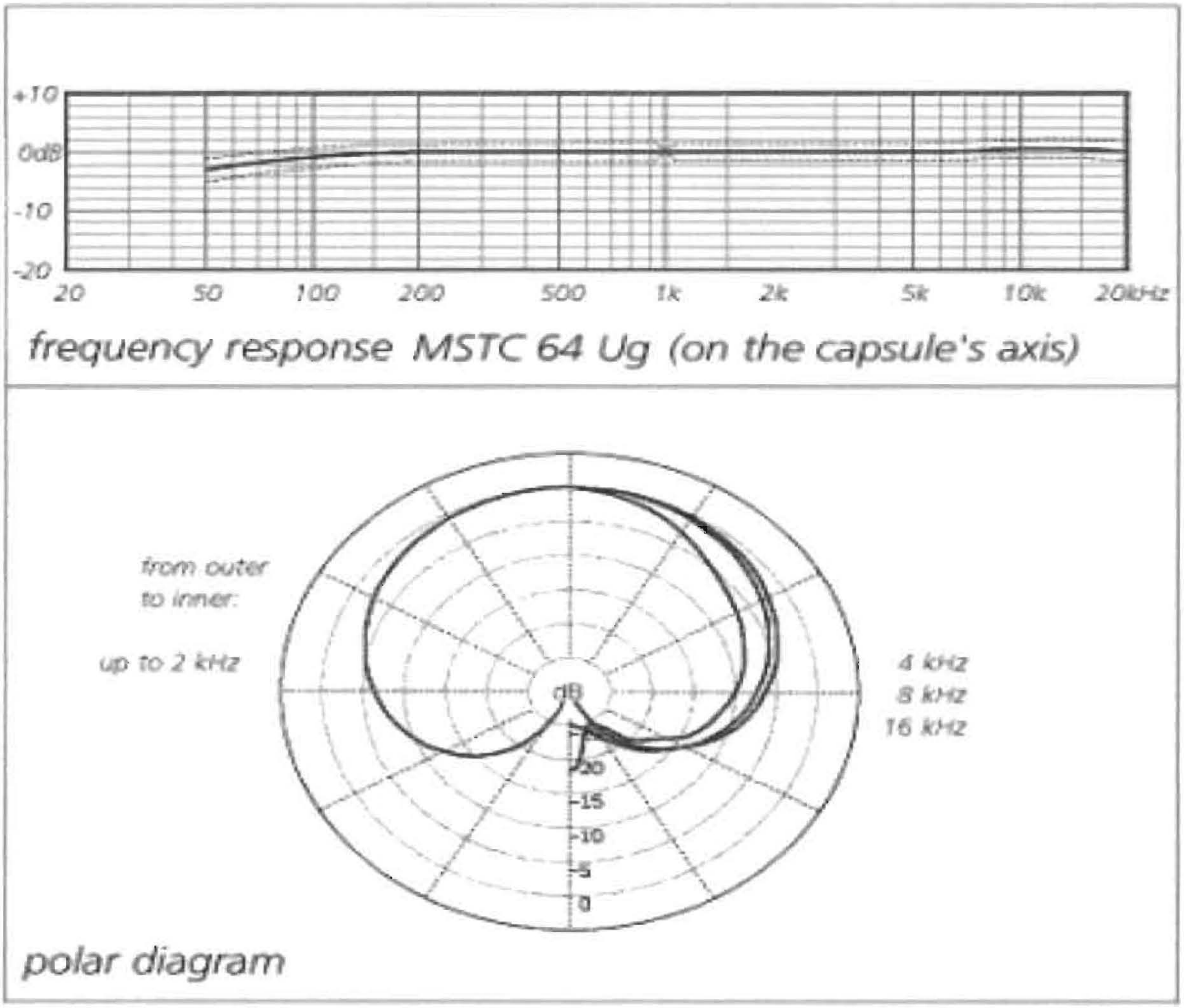

Figure 1: Frequency response and polar pattern of the Shoeps MSTC 64 U. [4]

Setting Up Shop

Before testing a car sound system, I wanted to test the microphone in a space with predictable results so I could compare the signal captured with the signal being put out. To do this, I used the MSTC 64 U to record the test signals in Ball State University's Mastering Studio in the Music Instruction Building. Below you can see the a frequency of white noise, first of the file itself(Fig. 2), then of the recording (Fig. 3)

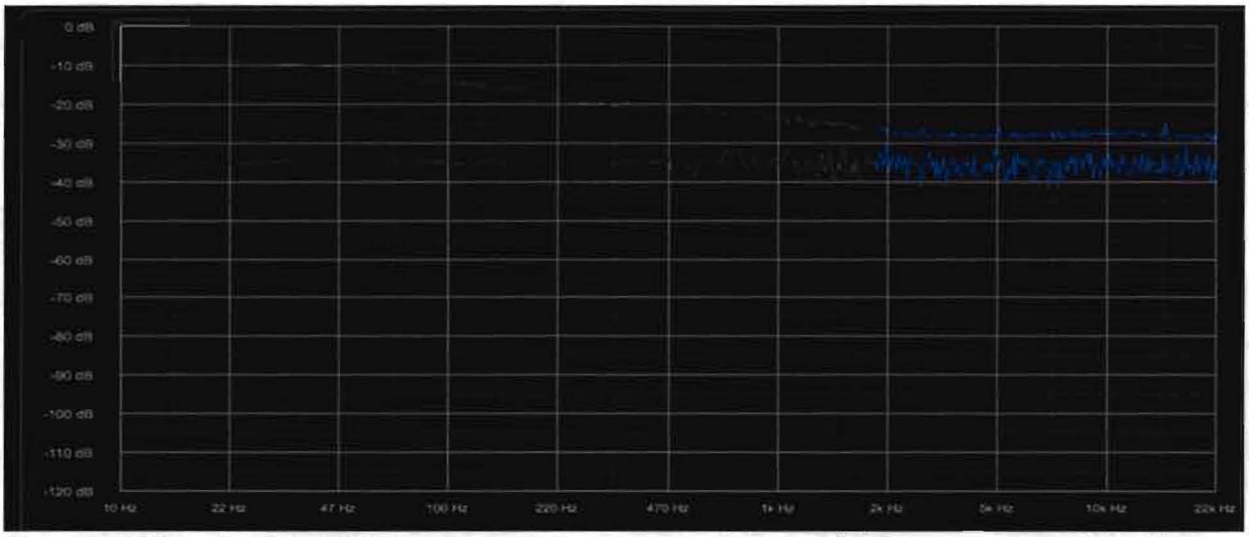

Figure 2: White noise frequency response. Notice how there is a very flat response across the entire spectrum. There is some variation, but those are instantaneous variations that come with the randomness of noise.

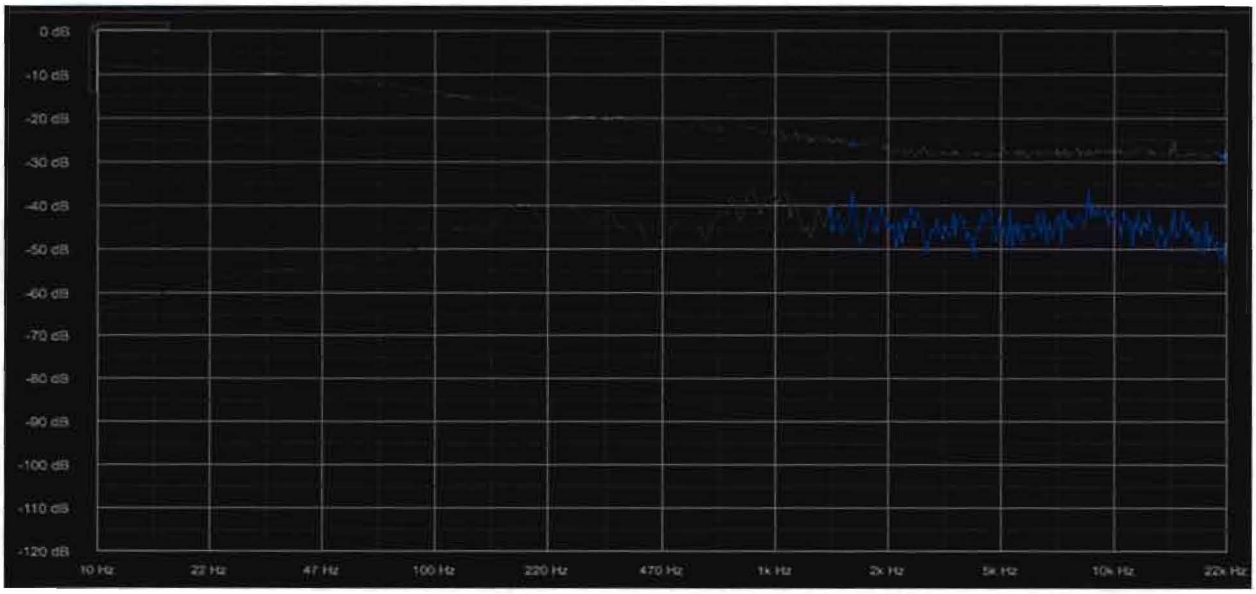

Figure 3: White noise recorded in Ball State's MMP mastering studio. Note the roll-off on the low end. This can be compared to the roll off of the microphone's low end seen in Figure 1 above.

As we can see from these tests, this particular studio reproduces sound very accurately, with a very flat frequency response and no standing waves or cancellations. Listening to the musical recordings of the room, one can hear very little room ambience. While setting up for the recording, however, I noticed that by placing the microphone equidistant from the speakers in the "sweet spot" that the microphone capsules angle out from the speakers. This meant that the microphone was not picking up sound from the speakers in a completely on-axis way. Looking at the polar pattern of the microphone seen in Figure 1, we can see that the microphone's pickup pattern becomes tighter as the frequency increases. This explains the gradual decrease of high frequencies as depicted in Figure 3.

Gentlemen, Start Your Engines

Now that we have a way to test a sound system, let's test some cars! I chose the 2015 Honda Fit as my vehicle, and I compared the sound system in the standard model with that in the premium model. I placed the microphone in the driver's seat of the car since someone should be in that seat every time the vehicle is being used. The microphone was placed in the center of the seat, 22.5 inches directly back from the dashboard. The microphone was 27 7/16 inches above the seat, and 9 3/18 vertically from the cabin ceiling. In both vehicles the temperature was between 80 and 85 degrees Fahrenheit. I attempted to keep them consistent, but I did not want the sound from the heater interfering with the tests. I set the equalizer to neutral to have the flattest signal possible. The volume was set to 20 out of 40 in the vehicle, which translated to white noise output at around 70.8 decibels. The output of the system was recorded numerous times with the engine running, and then with the engine off. In Figure 4 we can see the results of the standard four-channel system putting out white noise. In this instance the engine is off.

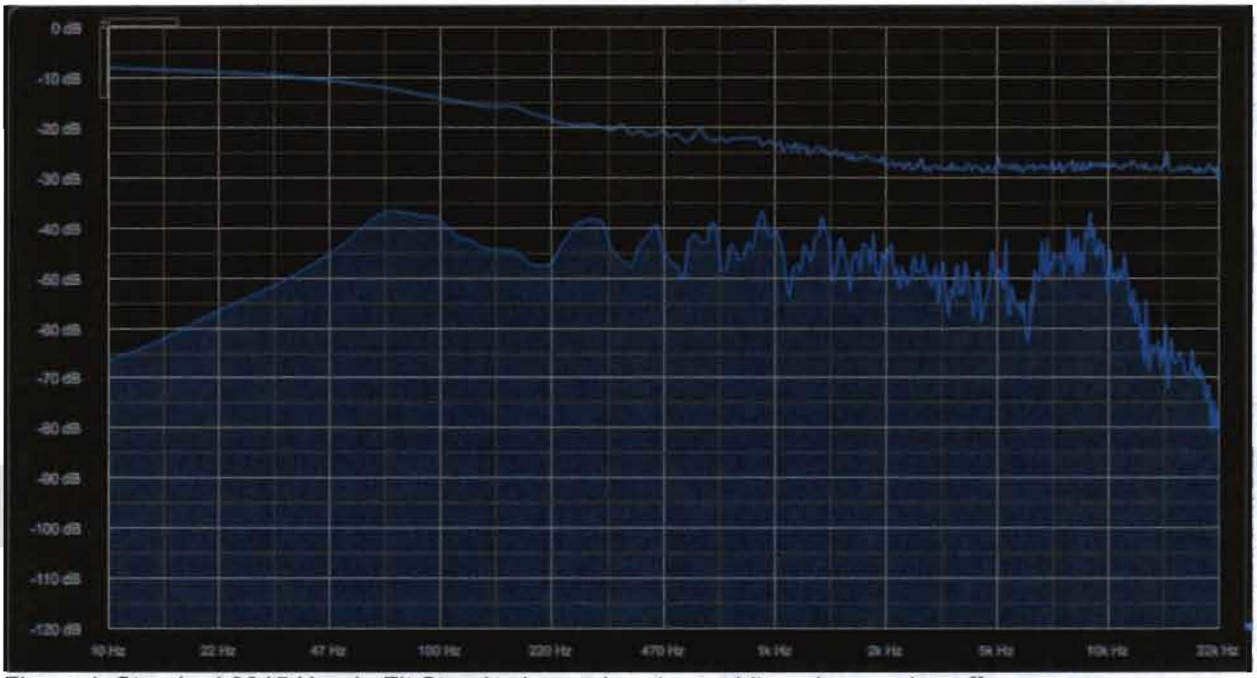

Figure 4: Standard 2015 Honda Fit Standard sound system, white noise, engine off

We can see immediately that there is a steep cut off of high frequencies above 10 kHz. This roll off is much steeper than that seen in Figure 3 with the control test. The low-end rolls off around 60 Hz. Decreased sensitivity is to be expected with this particular microphone, but not as dramatically as we see here. This can be explained by many factors, one of which being the material the speakers are made from. You can see another slight dip in the 2 kHz-6 kHz range. You might also notice that the spectrum looks a bit rougher than the control samples, with wider peaks and troughs. These occur at frequencies where phase issues cause cancellations or additions to amplitudes. These can be expected in just about any space, but they are wider and deeper

So know we can see how this particular car system works with the engine off. But who sits in the car without the engine off to listen to music? Let's take a look at a what white noise sounds like with engine noise thrown in the mix (Figure 5).

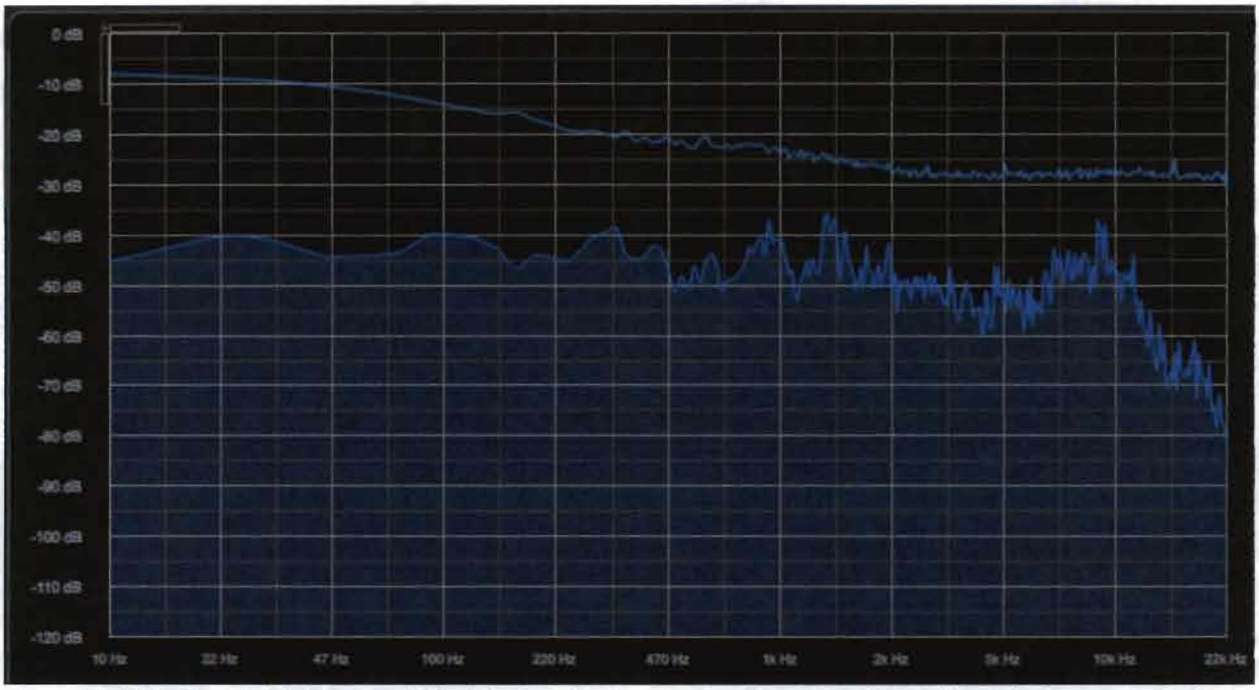

Figure 5: 2015 Honda Fit Standard Model. In thins instance, white noise is put through the car sound system, and the engine is running.

Not surprisingly, there is quite a bit more low frequency information in this recording that is provided by the car's engine. This large increase in low frequencies introduces the perceptual issue of masking. Masking is a phenomenon that occurs when there are multiple frequencies present, and some of them interfere with the ear's ability to hear others. [5] Low frequencies are particularly good at masking higher frequencies. So not only are the low frequencies lacking, but some of the lower-mid frequencies are more difficult to hear.

Along with the standard model, Honda released a premium model of the 2015 Fit that includes a six-channel sound system. Let's take a look at how it compares with the standard. These tests were conducted in matching conditions of the standard model test listed above. Figure 6 shows the frequency to white noise with the engine off, and Figure 7 shows the response to white noise with the engine on.

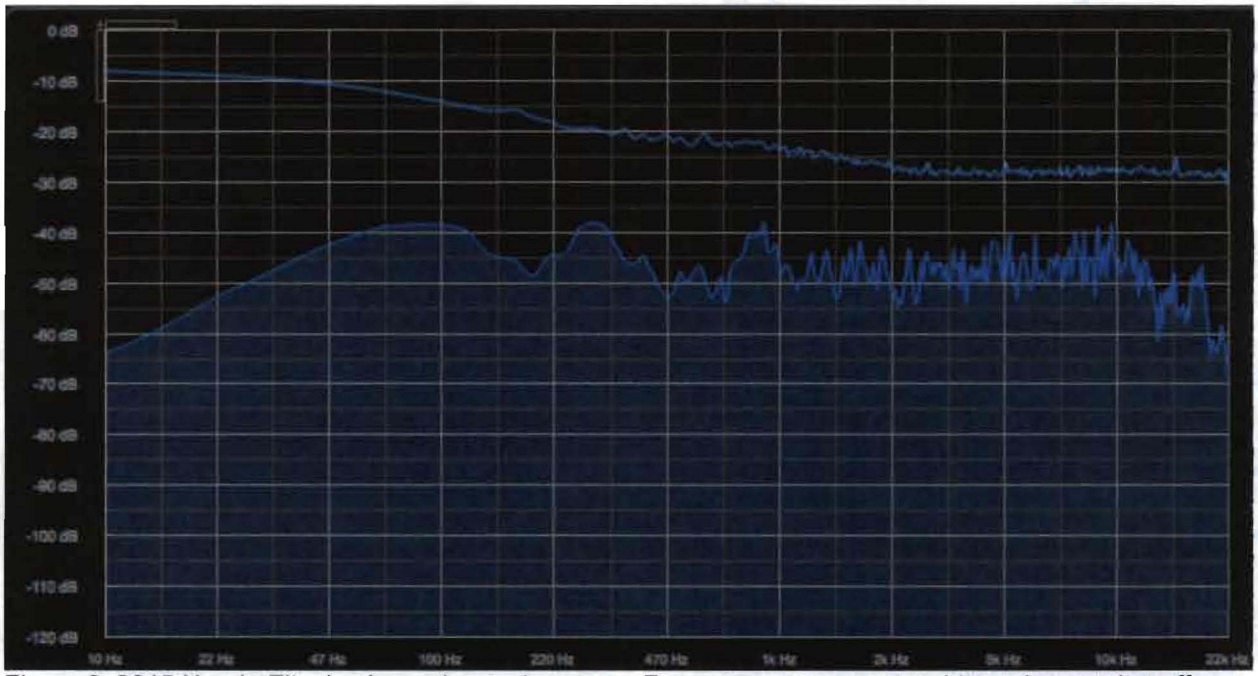

Figure 6: 2015 Honda Fit, six-channel sound system. Frequency response to white noise, engine off.

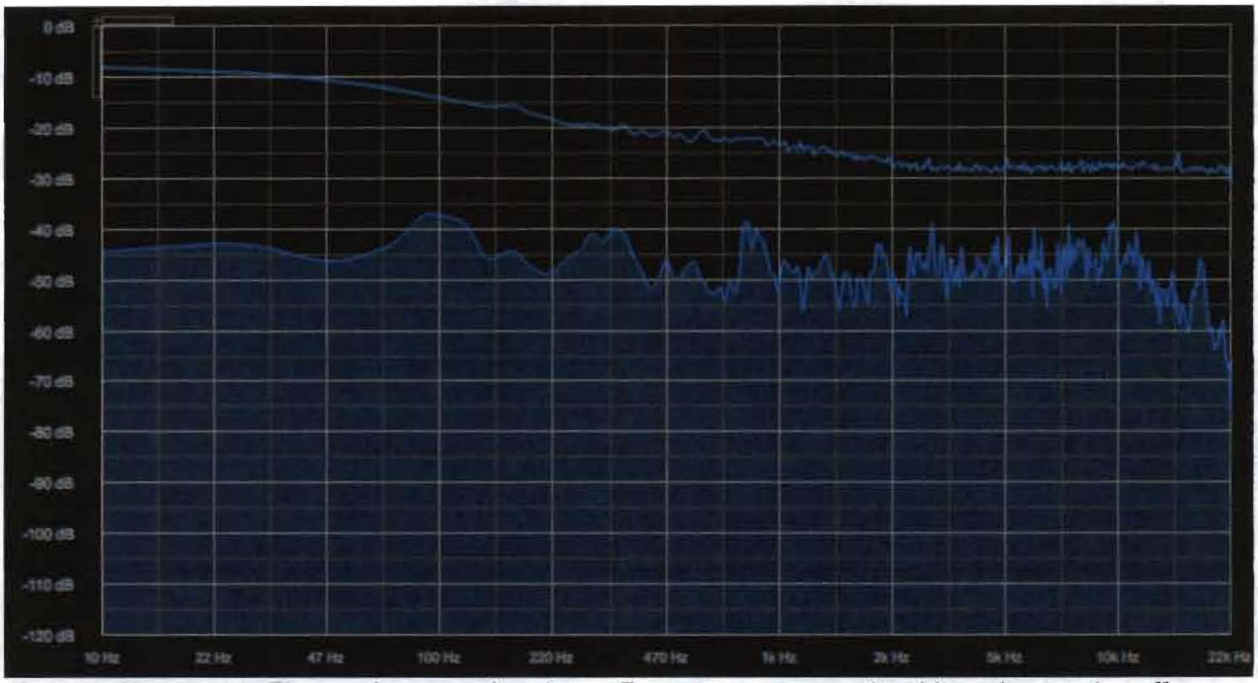

Figure 7: 2015 Honda Fit, premium sound system. Frequency response to white noise, engine off.

It is apparent that both with the engine off and with it on, the frequency response of the six-channel system is smoother than the response of the standard four-channel system. It still, however, isn't flat like white noise should be ideally. High frequencies start to decrease past 10 kHz, just as it does in the standard four-channel system. However, the roll-off in the high frequencies is much gentler in the premium system. One can also observe that the low frequency decrease is comparable, but the slope does appear to be more gradual. Listening back to the recordings I gathered, I personally couldn't hear a noticeable difference. All hearing is subjective, and I welcome readers to listen to the included recordings and make up their own minds.

Crank Up The Tunes

Using noise is good for testing a sound system's frequency response, as it has a predictable spectrum and any deviations can be easily seen. Music, however, does not have a constant and predictable frequency spectrum. For instance, let's take a look the frequency spectrum of a musical excerpt, shown in Figure 8.

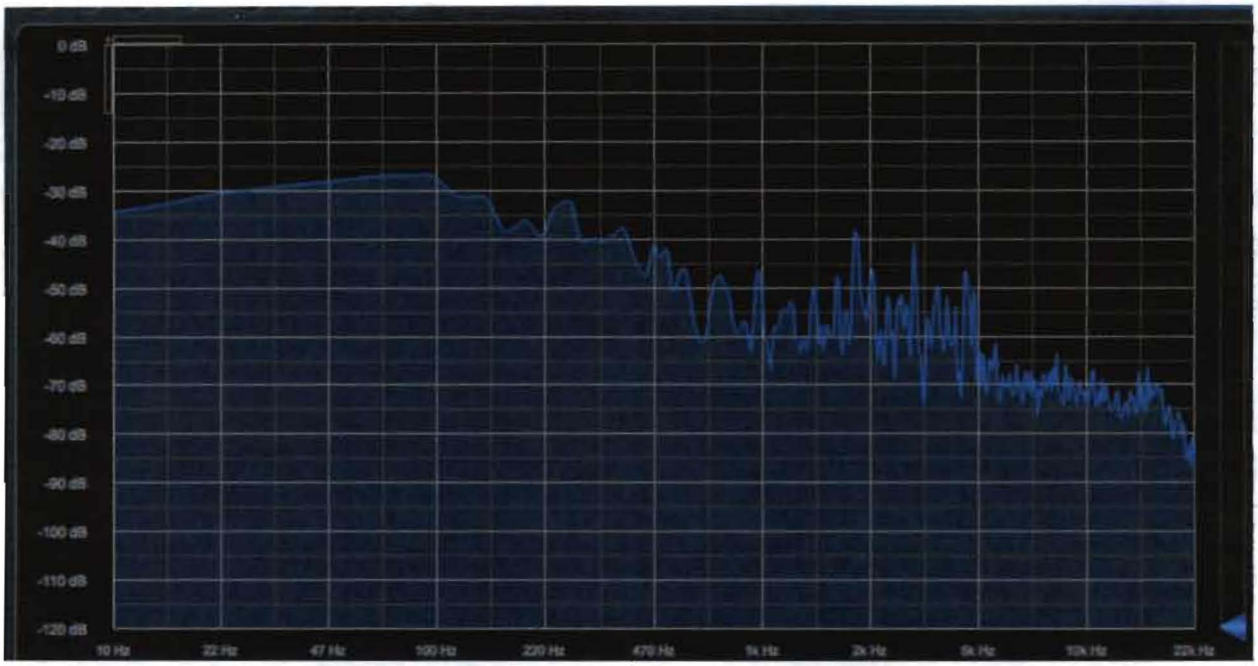

Figure 8: Spectrum of a moment of Daft Punk's "Get Lucky" (2013)

Clearly this spectrum looks nothing like any of the other figures shown previously. This is to be expected in music. Instruments go in and out, drum hits add a lot to the spectrum, and the sound of even one instrument can change drastically. If you notice that there is a gradual decrease in amplitude as the frequency increases. This is somewhat common in music, and the higher range of the audible spectrum often time contains mostly harmonics. So while white noise is good for objectively testing sound systems, it doesn't necessarily translate to what is heard. I would again encourage readers to listen to the enclosed recordings and make up their own mind.

Not to Sweep it Under the Rug...

You probably noticed a frequency sweep included in the list of recordings. I used that to try to identify resonances and cancelations in the car itself. When looking and analyzing them, I found that the response of those sweeps corresponded with the spectrum of the white noise tests. Looking at the previous images and identifying noticeable dips in amplitude, you can see many of the cancelations I found. I originally wanted to compare and contrast resonance frequencies to see if absorption in the car had an effect on what was heard, but after learning that the interior dimensions differed between the two, I shifted the focus of my research into the frequency response of the sound systems. However, I still used the sine-tone sweep in the test signals, and it can be informative to listen to them along with the other test recordings.

So What?

Now as an audio engineer, you're probably wondering what to do with this information. Do I change my mix to sound better in a car? Do I upgrade my current car system? Do I bother listening to mixes in my car anymore? You could apply a filter to your master bus to add more highs and lows, but at the expense of the mids that give your mix life and energy. Upgrading your car sound system can make a world of difference. In my opinion, you shouldn't change how you make music for the car, but how you *listen* in the car. No matter where you work on audio, be it a studio, venue, or apartment, the first step to a good sound is to know your environment. The same should hold true for cars. Get familiar with your car. Figure out what frequencies are strong and which are weak. Learn how it throws off your stereo imaging. Know why it makes your Grammy-worthy mix sound lifeless. Less than ideal listening systems can often be the most informative. For instance, the Yamaha NS10 monitors have a far from flat frequency response, but remain incredibly popular as reference monitors. Listen to your work every way you can, and you can make it sound good anywhere.

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